Lighting the Way Through Scientific Discourse

Students construct scientific knowledge through predictions, observations, and discussions.

Li-hsuan Yang

Many students can learn science formulas and use them to solve problems on exams, but they often do not know where the formulas come from or what their own "solutions" to the problems mean in a real-life context. Many students also believe that formulas provided in textbooks represent absolute truth, rather than something derived from empirical evidence and exchanges of ideas. In short, students may not realize how scientific knowledge is truly constructed. As science teachers, we must help students deepen their understanding of the nature of science, learn how scientific knowledge is constructed, and develop confidence and competence for engaging in scientific discourse.

In this article, I describe a thought-provoking lesson used in my classroom that compared various arrangements of lamp-battery circuits to help students develop the motivation and competence to participate in scientific discourse for knowledge construction. Through experimentation and discourse, students explored concepts about voltage, current, resistance, and Ohm's law (although this exact scientific terminology was not used). The discourse encouraged students to become deeply engaged in the process of making sense of their own observations and ideas.

Constructing scientific knowledge

It is important to help students experience, understand, and appreciate the process of constructing scientific knowledge—this often involves facing puzzling observations, asking genuine questions, proposing creative ideas, being engaged in scientific discourse, considering competing theories in light of evidence, and developing models to explain the phenomenon under investigation. This goal is shared by leading scholars and science educators in order to help students develop a deeper understanding of the nature of science (AAAS 1993; NRC 1996; Rutherford and Ahlgren 1989; Simpson 1997).

Experiments and discourse

In the lesson, students were first provided with various diagrams of specific lamp-battery circuit arrangements in order to make predictions about their potential for illumination. They then created the arrangements to observe and test their predictions. Throughout the lesson, students discussed their predictions and observations to exchange ideas and reach conclusions.

Students began with the diagrams found in Figure 1 (p. 54)—arrangements A, B, C, and D. They made predictions about which lamp(s) would turn on and then tested their predictions by making and observing each arrangement. After observing that only arrangement C illuminated the lamp, students quickly arrived at the conclusion that a complete circuit was needed to turn it on.

Having discovered the importance of a complete circuit, students went on to explore arrangements E, F,

and G, using arrangement C as a comparison (Figure 2). Students were asked the question, "Would the lamp in each of the arrangements (E, F, and G) be brighter, dimmer, or the same as the lamp in arrangement C?" Almost all students predicted that the lamp in arrangement E would be brighter and the lamp in arrangement F would be dimmer than the lamp in arrangement C. They reasoned that arrangement E provided twice the amount of energy for the lamp to use compared with arrangement C, making the lamp brighter. Whereas in arrangement F, the same amount of energy available in arrangement C had to instead be shared by two lamps, making the lamps dimmer.

This idea of "the same amount of energy being shared" seemed consistent with their observations when students created the arrangements and saw that the lamp in arrangement E was indeed brighter than the lamp in arrangement C, and that each of the two lamps in arrangement F was dimmer than the lamp in arrangement C.

However this hypothesis was soon challenged by their observation of arrangement G. Based on their hypothesis of "the same amount of energy being shared," most students predicted that lamps 3 or 4 in arrangement G would be dimmer than the lamp in arrangement C. When they saw that lamps 3 and 4 in arrangement G each showed the same brightness as the lamp in arrangement C, students felt the need to modify their hypothesis of "the same amount of energy shared." Some students started to think more about the way electricity flows. (**Note:** The following discourse was recorded from memory right after it occurred in the lesson.) The discourse demonstrates that students started to consider the ideas of push (voltage), resistance, and pathways (wires in circuits).

David: Arrangement F has two lamps, so it has more resistance than arrangement C, making the lamps in arrangement F dimmer under the same battery push.

Sharon: I thought lamp 1 would be brighter and lamp 2 would be dimmer because the electricity would reach lamp 1 first and be used up there, making lamp 2 dimmer. I guess this is not the case according to what we saw.

David: I do not think electricity would be used up by lamp 1. Whatever amount of electricity that flows to lamp 1 has to come out and flow through lamp 2 and then go back to the other end of the battery.

Madeline: But arrangement G also has two lamps, why does that not make the lamps dimmer?

Larry: Arrangement G has two pathways for the electricity to flow through. When you have two pathways, more electricity is flowing through the system.

Jane: I think the two lamps in arrangement G draw more electricity out of the battery.

Helen: What do you mean by drawing more electricity? Why are the two lamps in arrangement F not drawing more electricity out of the battery?

David: The two lamps in arrangement F are connected one after the other. Each lamp has its resistance, so two of them connected like that create more resistance. It is harder for the electricity to flow through.

Madeline: Then why do the two lamps in arrangement G not cause more resistance?

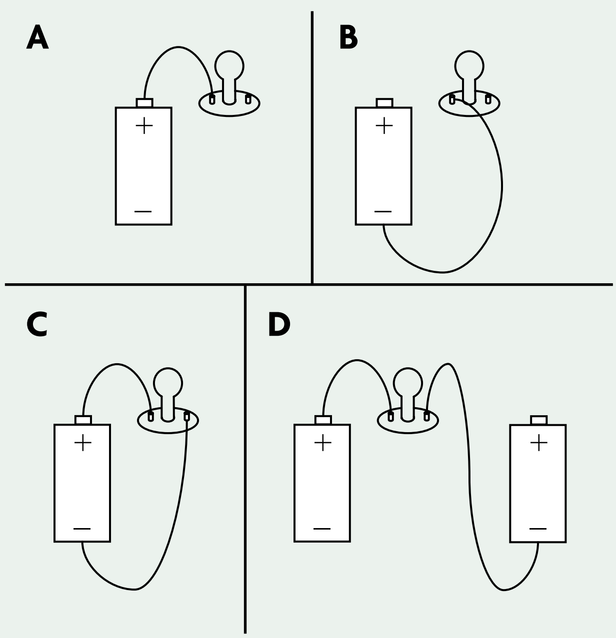
Larry: The two lamps in arrangement G have two pathways. It is like when you have a traffic jam. Once you have opened up a new road for the cars to go through, more cars can go through. Arrangement G has that new road!

Throughout the discussion, students gradually agreed that lamps connected one after the other (in a series) increased resistance and decreased the electricity flow, but lamps connected in parallel pathways allowed more electricity to flow through the system per unit of time because more "roads" were created for the flow.

After this concept was accepted by our learning community, students were asked to compare arrangement H to arrangement F (Figure 3, p. 56) and consider the question: "Will the light of lamp 5 in arrangement H be brighter, dimmer, or the same as the light of lamp 1 in arrangement F?" The following heated discussion started when students considered this question:

FIGURE 1

Arrangements A, B, C, and D.



Madeline: I think lamp 5 [Figure 3, p. 56] is going to be dimmer than lamp 1 because the energy is more spread out.

Tera: I think they are going to be the same because the electricity will reach the first lamp (lamp 1 in arrangement F or lamp 5 in arrangement H) before it spreads out, so the split should not affect the first lamp.

David: I think it depends on which direction electricity flows. I agree with Tera if electricity flows from the positive end to the negative end of the battery, because as Tera said, it will reach lamp 1 or 5 first before it spreads out. But if electricity flows from the negative end to the positive end of the battery, the two lamps (lamps 6 and 7) will draw more electricity than that one lamp (lamp 2), and later on the electricity going through the two lamps (lamps 6 and 7) would join together. That should make lamp 5 brighter than lamp 1.

Many students seemed to think that David's argument was very inspiring. Following this discourse, students made arrangements F and H and found out that lamp 5 was brighter than lamp 1. Some students were truly puzzled, others thought David's idea was right, but Larry had a different thought.

Larry: I do not think that direction matters. You can put lamps 6 and 7 closer to the positive end of the battery and move lamp 5 close to the negative end of the battery, and that should not make a difference.

The class decided to try Larry's suggestion and found out that he was right—it did not make a difference. Students who thought David's idea was right were now puzzled.

Gary: Remember that we found out more pathways will allow more electricity to flow through the system. Arrangement H has more pathways.

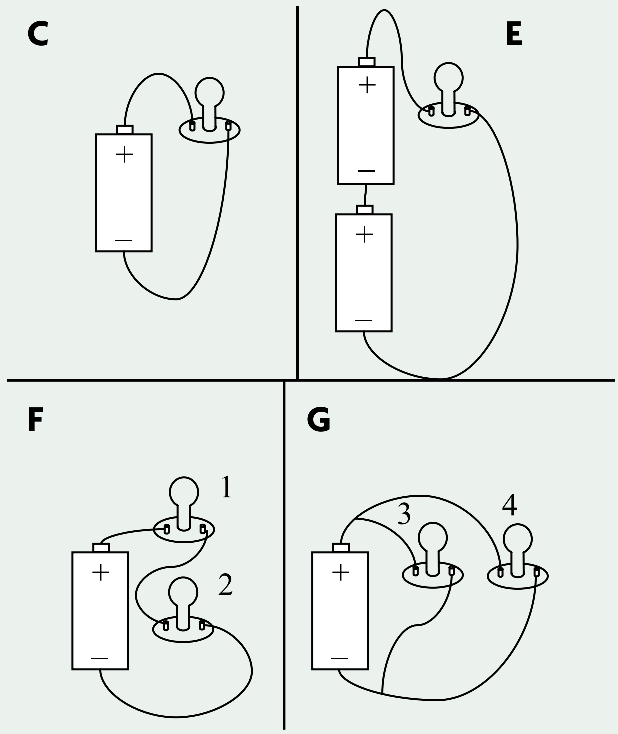
Jennifer: I understand what you are saying, but I do not understand why the electrons at one end of the battery would know that later on they will have more pathways to go through; therefore they start to move faster before they even reach the two pathways.

Kim: It is not that they know what is going to happen later on. It is like what Larry said. When you have a traffic jam and you open up a new road for the cars to go through, you naturally get more flow and that allows the cars behind to move faster.

John: You are all talking about more pathways. What about the lamps? Did we not say that more lamps create more resistance? Arrangement H has more lamps!

FIGURE 2

Arrangements C, E, F, and G.



Larry: We said that more lamps create more resistance when they are connected one after the other, like in arrangement F. But in arrangement H, lamps 6 and 7 are not arranged one after the other. Each one of them has an independent pathway to the battery.

Helen: I am not sure if they are independent though. The two pathways join and pass through lamp 5.

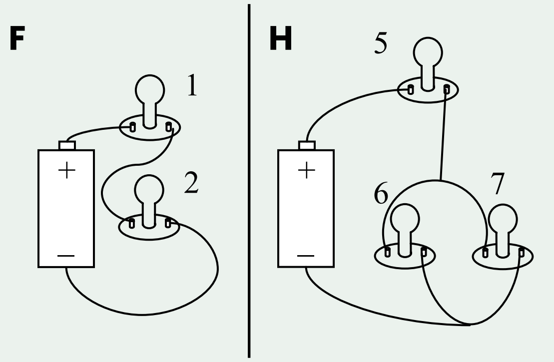
Kim: Yes, the two pathways join and pass through lamp 5. Think about this! When we compared arrangements F and G, we found out that lamps 3 and 4 each had an independent pathway to the battery and that allowed more electricity to flow through the system. Why do we not look at lamp 5 as an "indicator" of that flow? It should be brighter than lamp 1 because the two pathways (lamps 6 and 7) allow more electricity to pass through lamp 5.

Conclusion and discussion

Understanding how electricity and circuits work can be challenging for many students (McDermott and Shaffer 1992; Slater, Adams, and Brown 2000). Therefore I was absolutely fascinated seeing my students engaged in this science conversation. Students were so involved in the exchange of ideas that I rarely needed to even facilitate the discussion.

FIGURE 3

Arrangements F and H.



Concepts explored.

Voltage: A measure of the electric potential difference between two points in space, a material, or an electric circuit.

Current: A flow of electric charges through a conductor.

Resistance: The property of a material that resists the flow of electric charges through it.

Ohm's law: The current through a conductor between two points is proportional to the voltage across the two points and inversely proportional to the resistance between the two points, expressed as: *Current = voltage/resistance* or $I = V/R$.

I believe that this was because students were genuinely intrigued by the puzzling comparison between lamp 5 in arrangement H and lamp 1 in arrangement F. Students were eager to share their ideas and reasoning. They also proposed possible empirical studies to test their ideas. This exchange was made possible because the class had established an atmosphere that encouraged everyone to ask questions and to propose creative ideas with no fear of being thought of as "dumb" (Smithenry and Bolos 1997). Through discussion, exchange of ideas, and experimentation, students were able to uncover and empirically test the validity of alternative ideas, much as professional scientists do.

Traditionally, students' alternative conceptions are often viewed as something that interferes with learning the intended science concepts (diSessa 2006). In the scenario described in this article, we see that alternative conceptions served as the foundation and inspiration for the development of more sophisticated and accurate concepts (Hamza and Wickman 2008; Smith, diSessa, and Roschelle 1993).

Although I cannot claim that this class of students all developed a thorough understanding of Ohm's law (see "Concepts explored") because of this lesson, I do believe that their understanding of circuits and electricity has become much richer than what a formula such as $I = V/R$ can represent (Duckworth 1991). This rich understanding appeared to develop when students argued for different ideas, listened to each other's reasoning, tested their ideas with empirical observations, and reflected on how they knew what they knew (Korb, Sirola, and Climack 2005). This experience seemed to help my students further develop the inquisitive attitude, confidence, and competence to participate in scientific discourse. Students also deepened their understanding and appreciation of the nature of science and their roles as science learners. ■

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